TRANSACTIONS
OF THE
ILLUMINATING ENGINEERING SOCIETY

FOUNDED IN LONDON 1909

INCORPORATED 1930

CONTENTS

	Page
The Colour of Fluorescent Lamps, by W. Harrison, B.Sc. *(Member)*	145
Additions to List of Members	174
Register of Lighting Engineers	174
Proceedings at Annual General Meeting	175
Sessional Meeting in London	177

VOLUME XIV.
No. 6 — 1949

32 VICTORIA ST.
LONDON, S.W.1

Annual Subscription to Non-members - £2.2.0
Price per Number to Non-Members - 5s. 0d.

The I.E.S. Council and Committees
Session 1948-1949

Council

President :—J. M. WALDRAM, B.Sc. (*Fellow*).

Vice-Presidents :—E. C. WALTON, B.Eng., Ph.D., E. W. MURRAY (*Fellow*), J. N. ALDINGTON, B.Sc., Ph.D. (*Fellow*).

Members of Council :—

Elected Members:—

C. J. ALLDERIDGE, A. D. S. ATKINSON, H. S. BARLOW, C. R. BICKNELL, H. BRIGHT, L. J. DAVIES, G. H. GILES, H. F. GILLBE, C. E. GREENSLADE, T. S. JONES, S. D. LAY, E. C. LENNOX, H. A. LINGARD, J. H. NELSON, A. J. P. PASHLER, A. G. PENNY, L. C. RETTIG, J. S. SMYTH, W. T. F. SOUTER, J. F. STANLEY, W. R. STEVENS, P. C. SUGG, S. G. TURNER, F. WALKER.

Ex-Officio Representatives of Centres:—

L. BURDES (*Bath and Bristol*), W. J. P. WATSON (*Birmingham*), J. S. CHILDS (*Cardiff*), S. G. BATT (*Edinburgh*), D. ROSS (*Glasgow*), J. DAVOILE (*Gloucester and Cheltenham*), J. D. GREEN (*Leeds*), F. JAMIESON (*Leicester*), O. C. WAYGOOD (*Liverpool*), H. ATHERTON (*Manchester*), H. L. JAMES (*Newcastle*), E. G. PHILLIPS (*Nottingham*), B. BINGHAM (*Sheffield*).

Hon. Treasurer :—
J. G. HOLMES.

Hon. Secretary :—
H. C. WESTON.

Hon. Editor of Transactions :—W. R. STEVENS.

All Past-Presidents of the Society are *ex-officio* Members of Council.

Committees

GENERAL PURPOSES COMMITTEE: J. M. Waldram (*President*), J. G. Holmes (*Hon Treasurer*), H. C. Weston (*Hon. Secretary*), J. W. T. Walsh (*Past-President*), E. C. Walton, E. W. Murray (*Vice-Presidents*), C. J. Allderidge (*Birmingham Centre*), H. Atherton (*Manchester Centre*).

PAPERS COMMITTEE: A. D. S. Atkinson, C. R. Bicknell, T. S. Jones, A. G. Penny, F. C. Smith, J. S. Smyth, P. C. Sugg.

EDUCATION COMMITTEE: R. O. Ackerley, H. S. Barlow, A. Cunnington, P. Good, C. E. Greenslade, W. J. Jones, S. D. Lay, J. T. MacGregor-Morris, F. C. Smith, W. R. Stevens, J. W. T. Walsh.

I.E.S. CODE COMMITTEE: R. O. Ackerley, C. R. Bicknell, J. H. Nelson, F. C. Smith, J. S. Smyth, W. T. F. Souter, J. F. Stanley, J. W. T. Walsh, H. C. Weston.

DEVELOPMENT COMMITTEE: R. O. Ackerley, A. D. S. Atkinson, T. S. Jones. S. D. Lay, A. G. Penny, L. C. Rettig, S. G. Turner.

AREAS JOINT COMMITTEE: One representative from each Centre.
Council's Representatives: C. R. Bicknell, J. H. Nelson, W. R. Stevens.

(The President, Hon. Secretary and Hon. Treasurer are *ex-officio* members of all committees.)

Secretary :—G. F. COLE, 32, Victoria-street, London, S.W.1.

The Colour of Fluorescent Lamps

By W. HARRISON, B.Sc. *(Member)*

Summary

The relation between the spectral distribution and colour rendering quality of illuminants is discussed with particular reference to the spectral distribution differences which can be experienced with white fluorescent lamps.

Because of the subjective nature of colour appreciation, factors such as colour preferences and colour contrasts are of great importance in fluorescent lamp colour design.

The respective functions of chromaticity co-ordinates and spectral band measurements are indicated. The colour of a fluorescent lamp itself can be accurately specified by its C.I.E. co-ordinates, and tolerances of any desired magnitude can readily be fixed. For an adequate specification of the colour rendering quality, however, it is necessary that the spectral distribution be known.

Eight spectral-band and chromaticity co-ordinate data are given for the principal phosphors employed in fluorescent lamps. A brief survey of the colours of natural daylight and incandescent light is included.

Reasons are given favouring the design of fluorescent lamp colours for general lighting service on the purple side of the black body locus, as evidenced in the Warm White and Natural lamps.

Recent developments in the application of fluorescent lamps to colour matching include fluorescent lamps with approximately 6,500deg.K black body spectral distribution and mixtures of blue fluorescent and incandescent light.

Contents

(1) INTRODUCTION.
(2) THE COLOUR RENDERING PROPERTIES OF ILLUMINANTS.
  (2.1) The effect of the colour quality of the illuminant on the colour of objects.
(3) SPECIFICATION OF THE COLOUR OF ILLUMINANTS.
  (3.1) Specification of the spectral distribution—The Eight Spectral-Band Method.
  (3.2) Specification of the colour of the composite light — trichromatic colorimetry.
  (3.3) Current practice in colour specification.
  (3.4) The function of chromaticity co-ordinates measurements.
(4) DAYLIGHT AND ITS SPECTRUM.
  (4.1) General considerations.
  (4.2) Spectral distributions of natural light.
(5) THE INCANDESCENT LAMP SPECTRUM.
(6) THE COLOUR OF FLUORESCENT LAMPS.
  (6.1) General considerations.
  (6.2) Factors to be taken into account in choosing fluorescent lamp phosphors.
  (6.3) Mixed phosphor lamps.
  (6.4) Fluorescent lamps with calcium halophosphate phosphors.
(7) THE CHOICE OF FLUORESCENT LAMP COLOURS.
(8) ARTIFICIAL DAYLIGHT FOR COLOUR MATCHING.
  (8.1) Developments in artificial daylight in Great Britain.
  (8.2) Blue fluorescent plus incandescent light mixtures.
(9) TRENDS IN FLUORESCENT LAMP COLOUR.

The author is with Siemens Electric Lamps and Supplies, Ltd., Preston. The MS. of this paper was first received on September 27, 1948, and in its revised form on December 14, 1948. The paper was presented at a meeting of the Society on March 8, 1949.

(1) Introduction

Not the least important of the features which have contributed to the success of the fluorescent lamp is the range of colours in which it can be produced at high efficiency.

The flexibility of colour control which is in marked contrast to the relative inflexibility of both incandescent filament and electric discharge lamps is, of course, due to the fundamental difference in the mechanism of light production. Some 80 per cent. of the light emitted by the fluorescent lamp results from the conversion of ultra-violet line-spectrum radiation into continuous spectrum light by the phosphor or fluorescent powder coating on the inside of the lamp bulb. A wide range of phosphors used either singly or in mixtures provides a correspondingly wide choice of colours.

The introduction of the fluorescent lamp made practicable the simulation of natural daylight at high efficiency and so it was logical that the first white fluorescent lamp should be of Daylight colour. Subsequently the demand for a warmer colour for some applications led to the introduction of the Warm White colour, and more recently the Natural colour has been introduced as an alternative to the Daylight lamp for applications where more pleasing rendering of colours is desired.

The first section of this paper is devoted to a survey of the principles involved in the assessment of the colour-rendering quality of an illuminant. The colour-rendering qualities of natural daylight and the incandescent filament lamp are then discussed. The remainder of the paper deals with the colour characteristics of fluorescent lamps and is illustrated by data on the principal phosphors and combinations, and a consideration of the colour of the various fluorescent lamps at present available.

(2) The Colour-rendering Properties of Illuminants

(2.1) The Effect of the Colour Quality of the Illuminant on the Colour of Objects

The colour of any object is determined by two factors, namely, the spectral quality of the light which illuminates the object, and the way in which the incident light is selectively transmitted or reflected. A coloured material may thus be regarded as a filter which absorbs light of some wavelengths and transmits or reflects the remainder. These principles were first explained by Sir Isaac Newton in a letter to the Royal Society in 1672 which contained the following passage:—

"The colours of all natural bodies have no other origin than this, that they are variously qualified to reflect one sort of light in greater plenty than another, and this I have expounded in a dark room by illuminating those bodies with uncompounded light of divers colours. For by that means any body may be made to appear of any colour. They have there no appropriate colour but ever appear of the colour of the light cast upon them, but yet with this difference, that they are most brisk and vivid in the light of their own daylight colour."

It is a matter of common experience how greatly the colours of materials can be altered from the accepted normal when they are illuminated by coloured light having a spectrum composed of a few intense lines or bands. Typical examples of such illuminants are the sodium and mercury lamps, and coloured fluorescent lamps employing zinc silicate or cadmium borate. Although the variations in the apparent colour of materials under different near-white illuminants are smaller and more subtle, the same principles apply. The colour-

rendering properties of an illuminant are closely related to its spectral energy distribution.

It is axiomatic that the appearance in daylight of a coloured material is its "true" or "undistorted" colour. Any change in colour, i.e., in hue, saturation or brightness, from what is regarded as the undistorted colour is, of course, an important effect of the illuminant. Slight colour distortion, however, does not necessarily give an unpleasant effect, it may be pleasing or displeasing according to which colours are emphasised and to what extent. The subjective nature of colour appreciation has to be taken into account in deciding what is acceptable.

The physical changes which take place in the colour of materials seen under illuminants having different spectral distributions can arise in two ways. Firstly, most materials reflect to a greater or lesser degree light of several different colours, i.e., the reflection curve for the material extends over a broad band of the spectrum and hence there is a change in hue or saturation or both when the reflected light has a different spectral distribution. For example, red materials appear more saturated in incandescent light than in daylight because the proportion of red in the reflected light is higher. Secondly, there may be a change in the brightness of a colour relative to that of other colours. "Reds" appear relatively brighter in incandescent light than in daylight because the incandescent spectrum contains a higher proportion of red light. On the other hand "blues" appear less bright in incandescent light.

Another important factor is the well-known phenomenon of simultaneous colour contrast. The sensation produced by one colour stimulus may be modified by the presence of a second colour stimulus. If one colour is emphasised and there is insufficient colour contrast the effect is usually insipid and disappointing. The contrast of various parts of the face, for instance, plays an important part in the rendering of the colour of the human complexion.

One of the most important requirements of an illuminant is that it shall render "yellows" in a natural manner, because the human complexion and many common articles of food, e.g., butter, tea, and biscuits, may be described as yellowish in colour. The apparent colour of such things is of special importance, and so offers a test of the acceptability of the colour-rendering quality of an illuminant.

It is important that such articles should not be made to appear unnatural by over-emphasis of the yellow component of the spectrum. Over-emphasis of "greens" and "yellows" usually gives a not-too-satisfactory effect. In a study of colour preferences it has been found that "blues" and "reds" are preferred above the "greens" and "yellows" (1). A spectrum with adequate blue and red content and the other colours in well-balanced proportions is thus indicated as a desirable characteristic of an illuminant for general lighting.

The above brief consideration of how the appearance of colours depends on the spectral quality of the illuminant will, it is hoped, have indicated that, in addition to the purely physical effects, physiological and psychological ones are involved. It follows that the colour-rendering quality of an illuminant can generally be judged in the first place only by experience—that is, by seeing what things look like under the illuminant in question.

Factors of importance in making such an assessment are:—

(1) The illuminated scene should be similar to that for which the illuminant will be used.

(2) Experienced observers are preferable, because the differences may be relatively small.

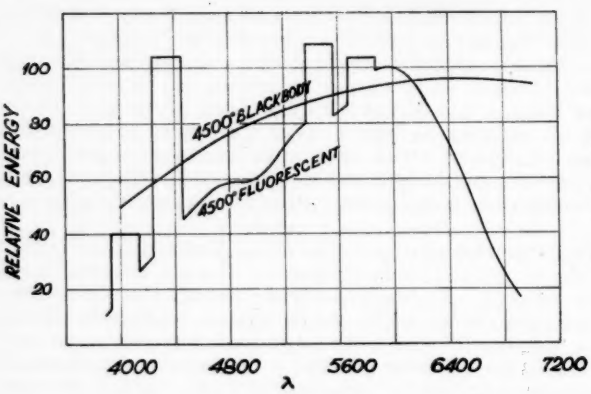


Fig. 1. Comparison of energy distribution in the visible spectrum for 4,500 deg. K black body and 4,500 deg. K fluorescent lamp.
(Illuminating Engineering, 1947, XLII., p. 415).

(3) An adequate number of observers should be used, as personal preferences can play a large part in the judgment of colour acceptability.

Physical measurements of the spectral distribution of an illuminant are chiefly valuable for purposes of specification. Two illuminants which have identical spectral distributions will, other factors being constant, give the same rendering of colours.

It is possible, by accumulated experience, to judge what differences in colour rendering will occur with two illuminants having different spectral distributions.

(3) Specification of the Colour of Illuminants

(3.1) Specification of the Spectral Distribution—the Eight Spectral Band Method

The spectral distribution data for an illuminant may be recorded as a full energy curve, such as is shown in Fig. 1. A practice in this country, however, is to use a method of abridged spectrophotometry in which the percentage luminance* in eight wavebands is measured.

These wavebands are as follows:—

Spectral Band No.	Waveband O.A.U.	Colour
1	3,800–4,200	Violet
2	4,200–4,400	Violet
3	4,400–4,600	Blue
4	4,600–5,100	Blue–Green
5	5,100–5,600	Green
6	5,600–6,100	Yellow
7	6,100–6,600	Light red
8	6,600–7,600	Dark red

The development of the eight-band method, as well as the apparatus for

* The term "percentage luminance" is used in this paper as the equivalent of "percentage of the total luminous flux." The term "percentage luminosity" was formerly used, but it has been suggested that "luminosity" should be used only as the subjective correlate of "luminance."

making the measurements, has been described elsewhere, and therefore need not be described here in any detail (2, 3, 4).

Some advantages of the use of eight bands are:—

(1) The subdivision of the spectrum into eight bands has been found adequate for specifying the colour-rendering quality of fluorescent lamps.

(2) Measurements of eight bands can be made rapidly.

(3) Two sets of eight figures are more readily compared than are two full distribution curves.

(4) A set of eight figures is readily set down for record purposes.

In considering spectral band luminance data it should be remembered that the relative visual sensitivity near the ends of the spectrum is low, and so, even if all the bands have comparable amounts of energy, the luminance of the end bands will be low and the spectral band figures may appear negligible, whereas, in fact, all the bands will be of comparable *colour* importance.

The form of graphical representation adopted in this country for the eight spectral band data is shown in Fig. 2, where the luminance values are plotted on a logarithmic scale.

(3.2.) Specification of the Colour of the Composite Light—Trichromatic Colorimetry

It is possible to specify precisely the colour of the composite light emitted by a lamp, as distinct from an analysis of it by the spectro-photometric method, by determining its position on an identifiable colour scale.

It is now usual to specify the colour of an illuminant on the C.I.E. system, by which the colour is identified by its chromaticity co-ordinates (x, y, z).

The ability to specify a colour by its chromaticity co-ordinates follows from the fact that experimentally any colour can be sensation-matched by a

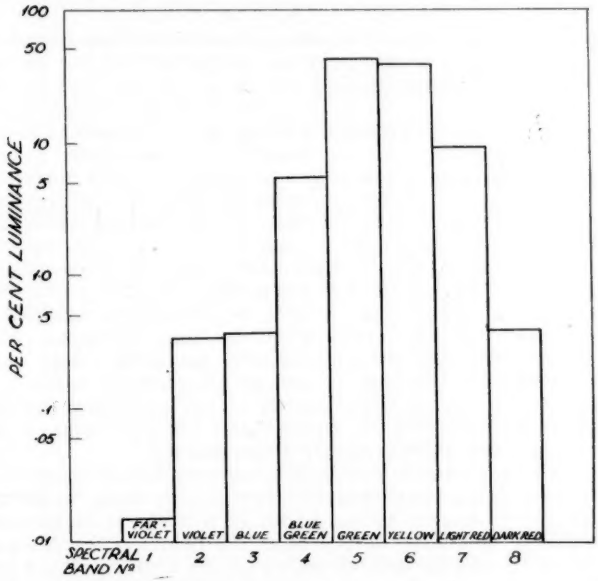


Fig. 2. Luminance distribution plotted on a logarithmic scale for a 4,500 deg. K lamp similar to that in Fig. 1.

mixture of red, green and blue light. Thus a colour match can be represented by a tri-chromatic expression of the form

$$C = rR + gG + bB$$

where r, g, and b, represent the proportions of R, G, and B.

$C = xX + yY + zZ$ is a particular form of this expression in which X, Y and Z are the reference stimuli defined by the C.I.E. for specification purposes and x, y and z are the proportions of X, Y and Z adjusted in magnitude so that $x + y + z = 1$.

It is possible to derive the values of x, y, and z for a particular composite radiation from the spectrophotometric data. It is important to note, however, that since the chromaticity co-ordinates specify only the colour of the composite light it is not possible to derive the spectral distribution data from the chromaticity co-ordinates.

The chromaticity co-ordinates alone therefore do not give a complete identification of the colour-rendering quality of an illuminant because although two colours may be an exact match to the eye, their spectral distributions can, and in many cases will, be different. For example, a fluorescent lamp of colour temperature 4,500 deg. K may not give light having the same spectral distribution as that from a black body at 4,500 deg. K (see Fig. 1) although the colour of the two lamps would appear the same to a standard observer.

(3.3.) Current Practice in Colour Specification

At the recent C.I.E. meeting in Paris a recommendation was made that the colour and colour-rendering properties of illuminants should be measured and expressed in terms of

(i) C.I.E. chromaticity co-ordinates.

(ii) Luminance in agreed spectral bands.

and that in view of established practice the spectral bands used should be provisionally those which have been quoted in 3.1.

(3.4.) The Function of Chromaticity Co-ordinates Measurements

Later, in discussing the various phosphors, it will be shown that fluorescent lamps employing different phosphors can have the same chromaticity co-ordinates but significantly different spectral distributions. Since a knowledge of the spectral distribution is necessary for complete identification of the colour-rendering quality, the specification by chromaticity co-ordinates is inadequate for this purpose unless linked in some way with spectral distribution data.

One way in which the colour quality of a fluorescent lamp can be more fully specified than by chromaticity co-ordinates alone is to quote in addition the exact type of phosphor used in the lamp. For example, if the light from the lamp is quoted as having certain chromaticity co-ordinates and the phosphor is stated to be a mixture of magnesium tungstate and a specified zinc beryllium silicate the colour quality will be adequately specified for general lighting purposes. Another lamp with the same phosphor and having the same chromaticity co-ordinates will have the same colour and nearly enough the same spectral distribution and colour-rendering quality. (N.B. It is necessary to specify the chromaticity of the particular zinc beryllium silicate, because this phosphor can be made in a range of hues. In general the chromaticity of magnesium tungstate is invariable.)

Chromaticity co-ordinates measurements are made more readily than the spectral band measurements—they can be made to an accuracy adequate for the closest control of the colour of fluorescent lamps—and it is easier to put working tolerances on the objective point on the chromaticity diagram than to specify appropriate tolerances for the eight spectral bands. As stated above,

if the type of phosphor is adequately defined in addition to the lamp chromaticity co-ordinates the colour quality of a fluorescent lamp is fairly well defined. Thus chromaticity co-ordinates measurements are the most suitable for day-to-day control of the manufactured product where the same phosphor is used.

The chromaticity diagram plays a useful part in research on fluorescent lamp colour, for by it the resultant colour from a mixture of phosphors can be determined. This application will be considered more fully in a later section (6.3).

(4) Daylight and its Spectrum

(4.1.) General Considerations

It is well known that natural daylight is very variable in intensity and colour, owing to the varying proportions of sunlight and skylight and the effect of clouds and the atmosphere. For example, the intensity of illumination out of doors can vary from less than one hundred to many thousands of lumens/ft.^{2} and, whereas the colour temperature of direct sunlight is approximately 5,000-5,500 deg. K, that of blue sky may be 20,000 deg. K or higher.

Why is it, then, that daylight, though so variable, is in all its various phases so acceptable for general illumination? The chief reason, probably, is that, whatever the colour temperature, the spectral distribution does not depart seriously from that of black body radiation at that temperature. The non-selective character of the daylight spectrum results in no undue emphasis of any particular colour and although there are differences in the colours of materials under the different phases of daylight, because their appraisal is to a large extent relative they appear "normal." In addition, the intensity of daylight is usually high.

(4.2.) Spectral Distributions of Natural Light

In Fig. 3 are shown energy distributions (due to Taylor and Kerr) for (a) daylight from a zenith blue sky of colour temperature 13,700 deg. K and (b) sunlight plus skylight of colour temperature 6,000 deg. K. In addition, for comparison is added the curve for (c) light from a gas-filled tungsten filament lamp at 2,848 deg. K (Standard Illuminant A).

Spectral band and chromaticity data for these illuminants are given in Table 1.

Table 1.

Spectral Band and Chromaticity Data for Daylight and Incandescent Light.

	Daylight 13,700 deg. K.	Daylight 6,000 deg. K.	Incandescent 2,848 deg. K. (Standard Illuminant A)	
Spectral Band No. 1 ...	0.052	0.025	0.0054	Percentage luminance
,, ,, ,, 2 ...	0.38	0.216	0.0585	
,, ,, ,, 3 ...	1.265	0.78	0.249	
,, ,, ,, 4 ...	13.85	10.5	5.39	
,, ,, ,, 5 ...	44.8	41.3	33.52	
,, ,, ,, 6 ...	31.8	36.3	42.68	
,, ,, ,, 7 ...	7.4	10.15	16.50	
,, ,, ,, 8 ...	0.45	0.73	1.52	
x ...	0.263	0.322	0.448	Chromaticity co-ordinates
y ...	0.279	0.335	0.407	
z ...	0.458	0.343	0.145	

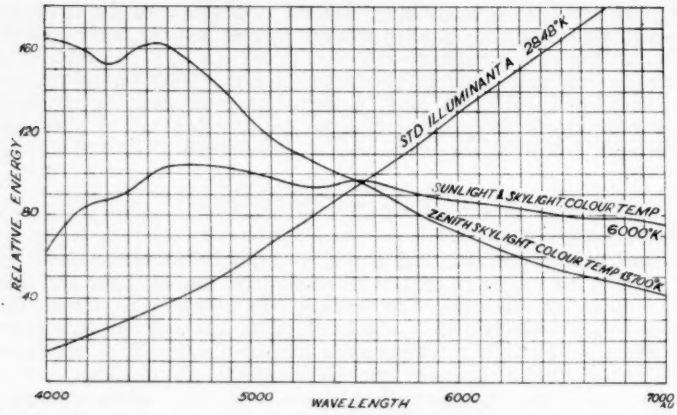


Fig. 3. Energy distribution curves for types of daylight and incandescent light. (Daylight curves due to Taylor and Kerr[6]).

(5) The Incandescent Lamp Spectrum

The spectral energy distribution of the incandescent tungsten filament lamp may be considered for all general purposes as identical with that of black body radiation at the same colour temperature and, as shown in Fig. 3, is represented by a smooth curve sloping upwards from the violet to the red end of the spectrum.

The colour temperature range in which filament lamps for general illumination are operated is about 2,600-2,800 deg. K (10-14.5 lumens per watt) which represents quite a small range of colour as shown by the following chromaticity co-ordinates.

Colour temperature	Approx. efficiency for gasfilled lamp	C.I.E. chromaticity co-ordinates		
		x	*y*	*z*
2,600 deg. K.	10 lumens/watt	0.468	0.412	0.120
2,800 deg. K.	14.5 ,, ,,	0.452	0.409	0.139

From Fig. 3 it may be noticed that the difference in spectral distribution between the incandescent spectrum and the sunlight plus skylight spectrum is roughly of the same order as the difference between the latter and the zenith blue skylight spectrum. Comparing these three illuminants for room lighting, the blue skylight is generally considered too cold. The sunlight plus skylight is probably the most pleasing, although it is often said that the incandescent colour is preferred for artificial illumination.

The reasons why the incandescent colour has been acceptable are twofold. Firstly, until recently, there was no alternative, and so it was accepted as a matter of course. The illumination of rooms with light of the incandescent colour has come to be accepted as normal, for this colour has been associated with artificial lighting through the centuries.

Secondly, it is a matter of experience that at low illumination levels the warmer colour is more acceptable than the daylight colour. The red content is high, giving pleasing rendering of the human complexion and a warmer

richer, colour to many materials. Also because the incandescent spectrum is continuous and regular, colour contrasts are satisfactory. To summarise, therefore, there is probably an optimum colour temperature for a black body or temperature radiator for the most pleasing rendering of colours, but illuminants of this type seem to be generally acceptable whatever their colour temperature, i.e., whether 2,600 deg. K or 60,000 deg. K. This may be attributed to the regular shape of the spectral distribution curve which gives satisfactory colour contrasts.

(6) The Colour of Fluorescent Lamps

(6.1) General Considerations

The colour of the light emitted by a fluorescent lamp is largely a function of the particular phosphor layer applied to the inside of the glass tube. The continuous spectrum due to the fluorescence of the phosphor accounts for about 80 per cent. of the total light, the remainder being contributed by the line spectrum of the low pressure mercury discharge. The ratio of mercury light to fluorescent light varies slightly with current density and so, for example, a lamp operating at 400 mA has a slightly different colour from one with the same phosphor operating at 800 mA.

The various phosphors which, singly or in mixtures, are employed in the fluorescent lamp are inorganic powders which are in most cases prepared to a very high degree of purity, and in some cases contain minute but critical amounts of additives. The degree of purity of the powder, the nature of the additives, and the particle size and shape affect to a remarkable extent the luminous efficiency.

The phosphors may be considered as the "palette" of the fluorescent lamp designer. There is, however, an important difference between mixing phosphors and mixing pigments. The former give additive colour mixtures whereas the latter give subtractive mixtures. Because phosphors emit light the addition of a new phosphor to a mixture broadens the spectrum of the resultant light or intensifies some part of it. But pigments absorb light and the addition of another pigment to a mixture reduces or narrows the spectrum of the reflected light.

(6.2) Factors to be Taken into Account in Choosing Fluorescent Lamp Phosphors

A point which has to be remembered when choosing the phosphor for a general purpose fluorescent lamp is that a very large proportion of such lamps is installed in industrial and commercial establishments. In such installations the primary requirement is for adequate illumination. If this can be combined with good colour-rendering quality all the better, but in general for lamps of similar colour but different efficiency, the choice will fall on the one having the higher efficiency. The choice of a phosphor depends on a number of factors, of which the colour-rendering quality is one. These factors may, to some extent, be conflicting and have to be weighed before a decision is made. The importance of the colour-rendering quality varies considerably according to the application of the lamps. In colour-matching work the colour-rendering quality of the illuminant is of first importance and the requirement is that its spectral distribution shall approximate as closely as possible to that of black body radiation.

In lamps designed for the lighting of shops, restaurants, theatres and the like the optimum colour and colour-rendering quality is an important requirement. In general for these and similar applications the most pleasing light is warmer than daylight, and where fluorescent lamps are to be used some

deviation from the black body locus on the purple side is generally desirable, at least with present phosphors.

An interesting problem is to determine what sacrifice in efficiency can be tolerated in return for a certain gain in the pleasing rendering of colours. Probably in most cases quite a large reduction in efficiency would be accepted for an illuminant of superlative colour-rendering quality. The eye can accommodate itself to a reduced level of illumination but is not so readily satisfied with regard to indifferent colour quality.

A high luminous efficiency is most readily obtained when the green and yellow content is high because the energy/light conversion factor is most favourable in the middle of the spectrum. For satisfactory rendering of colours, however, the blue and red content must be adequate, and hence an illuminant of good colour quality tends to have a lower luminous efficiency than one more rich in the yellow green region of the spectrum.

(6.3) Mixed Phosphor Lamps

Mixtures of phosphors of complementary colours can be employed for white fluorescent lamps. This is the practice in the U.S.A. and was also the general practice in this country prior to the introduction of the halophosphate phosphors. The most common mixture consists of magnesium tungstate (blue fluorescence) and zinc beryllium silicate (yellow fluorescence), but there are other phosphors which can be mixed together to give white light, as will be discussed later.

In Table 2 are given typical data obtained from lamps coated with various single phosphors. In this paper all data, except that on American lamps, refer to fluorescent lamps of dimensions 5 ft. x 1½ ins. operating at 80 watts.

It will be appreciated that the data are typical and that variations in spectral band values and chromaticity co-ordinates can occur, particularly with certain phosphors. The data on fluorescent lamps given in this paper should not be regarded as necessarily representative of commercial lamps.

Table 2.

Typical Data on Various Phosphors.

	Calcium Tungstate	Magnesium Tungstate	Zinc Silicate	Zinc Beryllium Silicate	Cadmium chloro-phosphate	Cadmium Borate	
Spectral Band No. 1	0.074	0.024	0.006	0.011	0.006	0.013	Percentage luminance
" " " 2	1.32	0.60	0.17	0.21	0.19	0.39	
" " " 3	1.84	1.01	0.04	0.04	0.02	0.03	
" " " 4	16.4	14.3	5.2	0.8	0.25	0.42	
" " " 5	56.5	54.8	80.8	38.2	20.8	20.0	
" " " 6	21.8	25.5	13.2	47.4	64.4	52.1	
" " " 7	2.05	3.6	0.55	12.7	14.0	25.9	
" " " 8	0.14	0.21	0.05	0.60	0.39	1.04	
x	0.193	0.234	0.230	0.468	0.469	0.543	Chromaticity co-ordinates
y	0.157	0.296	0.619	0.429	0.430	0.336	
z	0.650	0.470	0.151	0.103	0.101	0.121	

Fig. 4 shows the location of the above chromaticity co-ordinates on the chromaticity diagram.

Because mixtures of phosphors give additive mixtures of light it is easy to calculate the percentage luminance in spectral bands of the resultant light. If the amounts of the components are expressed in parts by luminance all that is

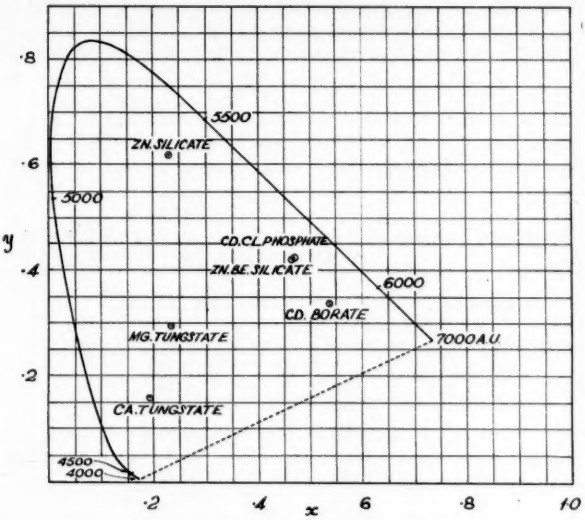


Fig. 4. C.I.E. chromaticity diagram showing co-ordinates of fluorescent lamps with single phosphors.

required is to add proportional parts of the spectral band luminances as given above and reduce to percentage luminance.

The C.I.E. chromaticity co-ordinates of a mixture are also readily obtained when the components parts are expressed in parts by luminance since the amount of light represented by a colour expression is associated with the Y stimulus. Consider, for example, a mixture of 100 parts by luminance of magnesium tungstate and 180 of zinc beryllium silicate. The calculation runs thus:—

	X	Y	Z
Put down chromaticity co-ordinates for Magnesium Tungstate.	0.234	0.296	0.470
Y for Zinc Beryllium Silicate is 180 per cent. of 0.296 and X and Z follow from the chromaticity co-ordinates.....	0.582	0.534	0.128
Total.....	0.816	0.830	0.598
Reduced to a unit equation	0.364	0.370	0.266

Thus the chromaticity co-ordinates of the mixture are:—

x	y	z
.364	.370	.266

It will be obvious that a similar summation can be made if three or more phosphors are employed in a mixture. The above calculation has employed the proportions by luminance of the components; in order to obtain the proportions by weight it is necessary to take into account the respective luminous efficiencies and powder densities.

The chromaticity of mixtures of various phosphors can be predicted from the chromaticity diagram. For if the chromaticities of two phosphors are represented by two points on the diagram the line joining the two points is

the locus for mixtures of the two phosphors. If a triangle is formed by joining up three points representing three phosphors, any colour represented within the triangle can be realised by appropriate mixture of the three phosphors.

Colorimetric data are given in Table 3 for two phosphor mixtures which give approximately the 4,500 deg. K black body colour, yet which have significantly different spectral distributions. Data for a total radiator at 4,500 deg. K and for a mixture of the light from a tungsten filament lamp and a fluorescent lamp coated with magnesium tungstate phosphor are also included.

Table 3.

Percentage Luminance, in Spectral Bands, of Various Illuminants having approximately the same colour as a Black Body at 4,500 deg. K.

Spectral Band No.	4500 deg. K black body	Magnesium tungstate + zinc beryllium silicate	Magnesium tungstate + zinc silicate + cadmium borate	Magnesium tungstate fluorescent + tungsten incandescent
1	0.018	0.015	0.015	0.012
2	0.175	0.35	0.40	0.24
3	0.56	0.38	0.37	0.50
4	8.75	5.5	6.6	8.4
5	39.2	44.0	48.3	40.6
6	38.4	39.6	32.5	36.9
7	12.0	9.4	11.4	12.2
8	0.89	0.40	0.49	1.08

A comparison of the spectral distributions of the illuminants of Table 3 which have the same colour shows that the nearest approach to black body spectral distribution is given by the combination of fluorescent magnesium tungstate and the tungsten filament lamp. The blue fluorescent lamps are particularly useful for combining with incandescent lamps to give light of near-black body spectral distribution, at colour temperatures in the daylight range. The blue end of the spectrum of the mixed light is provided largely by the fluorescent blue, and the red end of the spectrum by the incandescent lamp.

The three-phosphor mixture of magnesium tungstate, zinc silicate and cadmium borate is interesting from a colour point of view because the spectral energy distribution shows a peak in the green and a dip in the yellow bands compared with the 4,500 deg. K black body distribution. The luminous efficiency maintenance of this mixture is, however, generally not so good as that of the magnesium tungstate/zinc beryllium silicate mixture, and for this and other practical reasons this three-phosphor mixture is not used on any appreciable scale.

(6.4) Fluorescent Lamps with Calcium Halophosphate Phosphors

The phosphors known as calcium halophosphates were developed in this country. They are employed in most British lamps and are being introduced in the U.S.A. and are thus of great practical interest.

The calcium phosphate matrix can be activated by varying amounts of manganese and antimony compounds to produce a wide range of colours from pale blue to orange.

In addition, the luminous efficiency of halophosphate lamps is high, and the efficiency maintenance through life good; these factors make the halophosphates particularly valuable for general lighting service lamps.

Data obtained on a range of experimental halophosphate lamps are given in Table 4.

Table 4.

Data on Experimental Calcium Halophosphate Lamps.

		Light Blue	Blue-white	White	Orange	
Spectral Band No.	1 ...	0.029	0.017	0.015	0.009	Percentage luminance
,, ,, ,,	2 ...	0.66	0.48	0.35	0.30	
,, ,, ,,	3 ...	1.05	0.66	0.36	0.16	
,, ,, ,,	4 ...	14.8	9.2	5.4	2.2	
,, ,, ,,	5 ...	55.0	42.6	40.0	28.2	
,, ,, ,,	6 ...	24.5	38.4	45.1	56.0	
,, ,,	7 ...	3.8	8.3	8.5	12.8	
,, ,, ,,	8 ...	0.20	0.30	0.30	0.45	
	x ...	0.230	0.310	0.362	0.435	Chromaticity co-ordinates
	y ...	0.270	0.320	0.368	0.385	
	z ...	0.500	0.370	0.270	0.180	

(7) The Choice of Fluorescent Lamp Colours

The first white fluorescent lamps, both in America and in this country, were of Daylight colour with a chromaticity based on the black body locus.

Subsequently in America wide field experience has been obtained with the 6,500 deg. K Daylight, the 4,500 deg. K White, and the 3,500 deg. K White lamps, and it appears that the 4,500 deg. K White is the most popular of the three for general lighting.

The American 4,500 deg. K White and the British Daylight lamps have approximately the same chromaticity, but the phosphors used are different, most British lamps having phosphors of the calcium halophosphate type.

Fluorescent lamps of the Daylight colour have been found quite satisfactory for industrial and commercial installations, applications which have absorbed the greater part of fluorescent lamp production hitherto.

The development of the Warm White colour followed attempts to match the incandescent colour. Lamps which had the "incandescent" colour were produced, but because their spectral distribution was considerably different from the incandescent spectral distribution, the colour-rendering quality was found to be not too satisfactory. An improved colour-rendering quality was obtained by designing the Warm White, which has a chromaticity appreciably removed from the black body locus on the purple side.

The Warm White lamp has been found suitable for many applications where a warmer lighting is desired, and this is obtained at an efficiency of approximately four times that for the incandescent lamp.

The Natural colour has been introduced recently in Great Britain primarily as an alternative to the Daylight colour, to meet the need in shops and in social and domestic applications for a lamp giving pleasing rendering of colours. Both the halophosphate and the mixed phosphor Daylights have been based on a chromaticity objective of the 4,500 deg. K point on the black body locus. It has, however, been found that more pleasing rendering of colours can be obtained if the blue and red content of the illuminant is relatively high. The resultant chromaticity of such an illuminant inevitably falls on the purple side of the black body locus. An illuminant of this type is the American Soft White, introduced specially to give pleasing colour-rendering of foodstuffs and the like. The chromaticity point for this lamp is rather far removed from

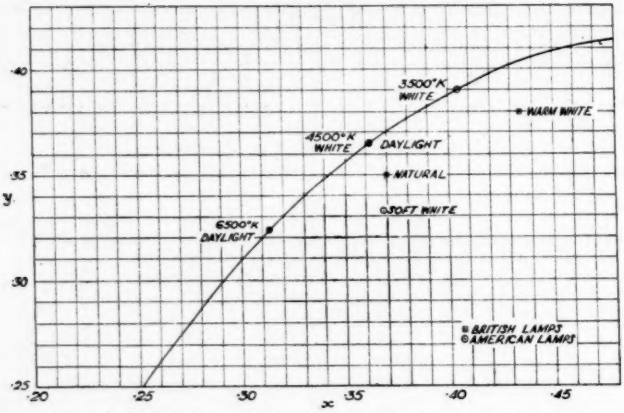


Fig. 5. Section of C.I.E. chromaticity diagram showing co-ordinates of typical white fluorescent lamps.

the black body locus, i.e., it is definitely purplish in colour, and its efficiency is appreciably lower than the 4,500 deg. K and 3,500 deg. K whites.

The chromaticity of the Natural lamp places it on the purple side of the black body locus but considerably nearer the locus than the American Soft White, i.e., the Natural is whiter than the Soft White. This may be seen from Fig. 5, which indicates the location of typical British and American commercial colours on the chromaticity diagram. It is again pointed out that the data should not be regarded as necessarily applicable to any particular commercial lamps.

The more pleasing rendering of colours by the Natural as compared with the Daylight lamp is attributable to the improved balance of its spectral distribution. Although the yellow content is high, the blue (violet) content is also high, and since these colours are complementaries the blue may be considered as neutralising the excess yellow. The Natural lamp gives good colour contrast because the blue content is adequate and the red content is also slightly higher than in the Daylight.

Because the chromaticity is not far removed from the black body locus (i.e., the lamp is a near white) and the efficiency is only a little below the Daylight value, it seems probable that the Natural lamp will prove attractive as a general purpose illuminant. Although there are many industrial applications where colour has not been considered of primary importance there is no doubt that good colour quality gives more pleasing working conditions.

(8) Artificial Daylight for Colour Matching

The introduction of the fluorescent lamp was a matter of great interest to those concerned with colour matching in this and other countries. The need for a satisfactory artificial daylight had long been felt, and it appeared that the possibility existed of using either the commercial Daylight or special fluorescent lamps for precise colour matching.

Some requirements have been, and are being, met by commercial Daylight fluorescent lamps, but the more critical colour matchings demand an illuminant with a spectral distribution approximating more nearly to that of true daylight

or black body radiation than the Daylight fluorescent lamps designed for general lighting purposes.

A considerable study has been made of illuminants for critical colour matching. The fields in which colour judging is of great importance range from the colour grading of raw materials to the dyeing and colour printing of finished products. Some of the work is extremely critical and it seems that hitherto most of it has been carried out under natural daylight. It is interesting to note that in the U.S.A. the preferred colour temperature appears to be approximately 7,000-8,000 deg. K (7. 8).

(8.1) Developments in Artificial Daylight in Great Britain

British artificial daylight developments were surveyed in a paper presented at the recent C.I.E. meeting (9). These follow two main lines:—

(1) Special daylight colour matching fluorescent lamps of either cold or hot cathode type, employing phosphors chosen primarily to give a spectral distribution approximating as closely as possible that of black body radiation. The colour temperature is usually 6,500 deg. K.

(2) The addition of light from a blue fluorescent lamp to that from one or more tungsten filament lamps to give light of approximately black body spectral distribution at any desired colour temperature.

The principle of the combination of blue fluorescent lamps and incandescent filament lamps will be considered in more detail in the next section.

(8.2) Blue Fluorescent Plus Incandescent Light Mixtures

In Fig. 6 is shown a section of the chromaticity diagram which illustrates the mixture of light from experimental blue fluorescent lamps and incandescent filament lamps to give artificial daylight. The line joining the magnesium tungstate position to the 2,700 deg. K position is the locus of the chromaticities of mixtures of the light from a magnesium tungstate fluorescent lamp and a 12-lumens-per-watt incandescent filament lamp. It will be seen that from 2,700 deg. K to 5,500 deg. K the locus of the mixtures follows approximately the

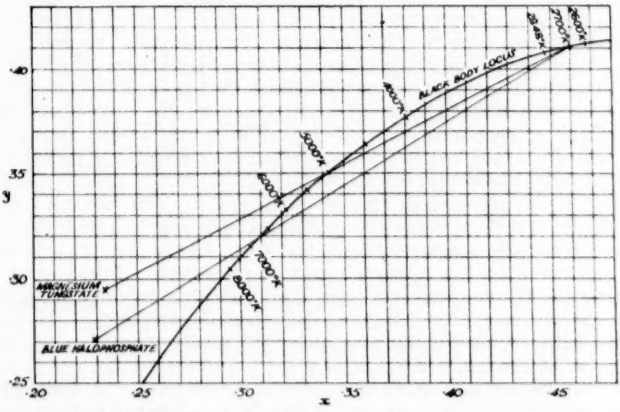


Fig. 6. Section of C.I.E. chromaticity diagram showing mixtures of blue fluorescent and incandescent light.

black body locus, hence black body radiation at any colour temperature in this range can be simulated by a mixture of appropriate proportions of light from magnesium tungstate fluorescent and incandescent filament lamps.

A similar mixture in which the magnesium tungstate fluorescent coating is replaced by the blue halophosphate is more suitable for the colour temperature range 5,500 deg. K to 8,000 deg K and for realising the Equal Energy colour.

The two blue phosphors mentioned above show good constancy of colour from batch to batch, i.e., the colour is reproducible; and since the colour of a tungsten filament lamp at a given efficiency is constant the mixtures are reproducible. Another point in favour of the mixture is that the spectral distribution is probably the nearest to black body distribution which can be obtained by means suitable to the illumination of a large area. Table 3 gives data on one of these mixtures and Table 5 gives a comparison of mixtures for 6,500 deg. K and Equal Energy with the illuminants they simulate.

Table 5.

Data on Experimental Mixtures of Blue Fluorescent Light and Incandescent Light. Percentage Luminance.

Spectral Band No.	46 per cent. tungsten at 12 L/W. 54 per cent. blue phosphate	6500 deg. K. Black body	55 per cent. tungsten at 12 L/W. 45 per cent. blue phosphate	Equal energy
1	0.017	0.032	0.016	0.028
2	0.365	0.26	0.33	0.229
3	0.66	0.83	0.61	0.738
4	10.2	10.65	9.6	9.66
5	44.5	41.81	43.2	40.1
6	33.4	35.77	34.5	37.1
7	10.0	9.90	10.75	11.29
8	0.85	0.68	0.92	0.86

(9) Trends in Fluorescent Lamp Colour

It is widely known, and has been perhaps almost over-emphasised, that the fluorescent lamp spectrum generally shows some deficiency at the red end. It has been one of the aims of this paper to indicate that the requirement for successful colour performance is a well-balanced spectrum: there is no doubt therefore that the discovery of a phosphor giving a high red content and satisfactory service would be most welcome. All the phosphors which can be used in high proportions in the white fluorescent lamps show a more or less steep fall-off in spectral bands numbers 7 and 8 relative to daylight. One line therefore along which research is proceeding is the search for phosphors which will give the desired increased red content. This search for new and improved phosphors may be said to be the more difficult line of research.

A second line of development is in the design of lamps of optimum colour-rendering quality with the present types of phosphors. Hitherto it has been considered desirable that lamps of the Daylight type for general illumination should have a chromaticity lying on the black body locus. It now seems, however, that the trend will be to design the white lamp colours slightly on the purple side of the black body locus.

The present paper has been largely concerned with the white fluorescent lamps used for general illumination. It should be added that for practical and economic reasons there is much to be said for limiting the range of colours

for this type of lamp to about three, e.g., 6,500 deg. K Daylight, Natural, and Warm White.

Acknowledgments

I desire to thank Dr. J. N. Aldington, Director of Research of Siemens Electric Lamps and Supplies, Limited, for permission to publish this paper.

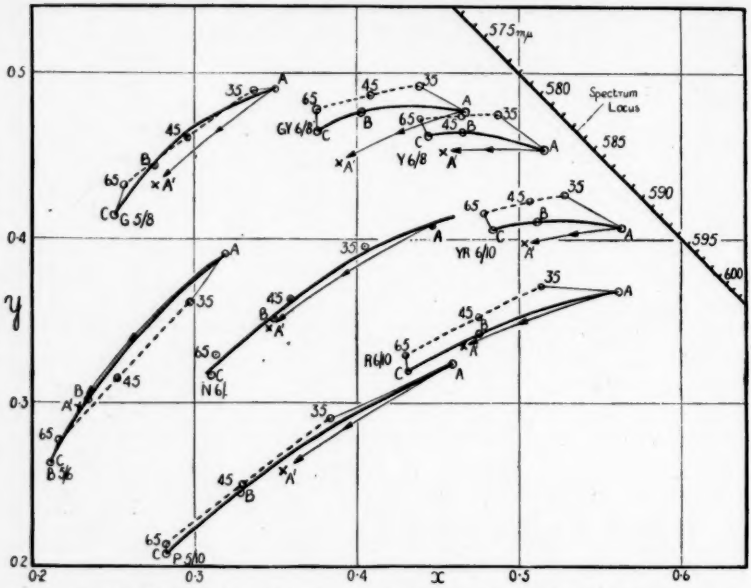
References

(1) Luckiesh, M. Colour and its Applications (2nd Ed.), p. 260.
(2) Winch, G. T., and Ruff, H. R. Measurements, Representation, and Specification of Colour and Colour Rendering Properties of Light Sources. Proceedings of the C.I.E., 1948.
(3) Winch, G. T. Photometry and Colorimetry of Fluorescent and other Electric Discharge Lamps. Trans. I.E.S. (London), 1946, Vol. XI, p. 107.
(4) Harrison, W. The Art and Science of Colorimetry. Siemens Engineering Bulletin (London), 1947, No. 231.
(5) Buck, G. B., and Thayer, R. N. Colour Technology of Fluorescent Lamps. Illuminating Engineering, 1947, XLII, p. 415.
(6) Taylor, A. H., and Kerr, G. P. The Distribution of Energy in the Visible Spectrum of Daylight. J. Opt. Soc. Amer., 1941, Vol. 31, p. 3.
(7) Nickerson, D. Artificial Daylighting Studies. Trans. I.E.S. (U.S.A.), 1939, Vol. 34, p. 1,233.
(8) Nickerson, D. The Illuminant in Textile Colour Matching. Illuminating Engineering, 1948, Vol. 43, p. 418.
(9) Winch, G. T., Harrison, W., and Ruff, H. R. Fluorescent Lamp Artificial Daylight Units for Colour Matching. Proceedings of the C.I.E., 1948.
(10) Buck, G. B., and Froelich, H. C. Colour Characteristics of Human Complexions. Illuminating Engineering, 1948, Vol. 43, p. 27.
(11) Detting, R. L., and Amick, C. L. Interpretation of Spectral Distribution Data in Practical Colour Applications. Illuminating Engineering, 1941, Vol. 36, p. 1,369.
(12) Kruithof, A. A. Kleuren en Kleurindrukken bij verlichtug met luminescentie-lampen (colours and impressions of colours in lighting with fluorescent lamps). Verslagen Symposia Ned. Nat. Ver., 1947, Nr. 2, p. 103.
(13) Wright, W. D. Colour in Illuminating Engineering. Trans. I.E.S. (London), 1947, Vol. XII, p. 1.
(14) Wright, W. D. The Measurement of Colour. (Adam Hilger, Ltd.)
(15) Hardy, A. C. Handbook of Colorimetry. (Mass. Inst. of Technology.)
(16) Bouma, P. J. Physical Aspects of Colour. (Philips Technical Publications.)

Discussion

DR. W. D. WRIGHT, in opening the discussion, said that he did not wish to comment in detail on the points made in the paper but he was extremely interested in the subject because it seemed to him that it was this sort of subject in which colorimetry came into its own; and it was refreshing to him to find that colour equations and chromaticity charts were really being used as tools in the design of lamps and the assessment of merits of light sources. What he wished to do, therefore, was to amplify some of the possibilities inherent in colorimetry.

At Imperial College they had been preparing chromaticity charts on which the Munsell patterns were shown and he thought it would be interesting to show how the chromaticity charts could be made more realistic in this way. (Dr. Wright then exhibited and explained a number of the charts in question.) Continuing, he said he had received from Miss Nickerson in America a considerable amount of data on the colour specification of the Munsell patterns under various types of fluorescent lamp and he understood that much of this



Section of the C.I.E. chromaticity chart showing the chromaticities of 8 of the Munsell patterns under 6 different illuminants. For each pattern the locus of the chromaticities under the standard illuminants A, B, and C, is shown by the full line and the points marked by the letters A,B,C. The locus under the American fluorescent lamps, the 6,500 deg. K daylight, the 4,500 deg. K white and the 3,500 deg. K white, is shown by the dotted line and the points marked by the numbers 65, 45, and 35. The Munsell specification of each pattern is given at the lower left hand end of the locus. The arrowed line from A to A^1 shows the change in the apparent chromaticity of the pattern under illuminant A when seen by an "A-adapted" eye, as estimated from work by Helson and Grove.

data was shortly to be published in the journal of the American Illuminating Engineering Society.

He had plotted the results for eight of the patterns in the accompanying diagram. This showed the chromaticities of the patterns under the standard illuminants A, B, and C and also under the American fluorescent lamps—the 6,500 deg. K daylight, the 4,500 deg. K white and the 3,500 deg. K white, which had already been illustrated in Fig. 5 of Mr. Harrison's paper. The enormous change in chromaticity of the patterns with illumination was very evident, both for the standard illuminants and the fluorescent lamps, but perhaps the most interesting feature was the divergence of the fluorescent locus (dotted line) from the A-B-C locus (full line) for the colours on the red—yellow—green side of the chromaticity chart. The divergence was in the sense that at the lower colour temperatures the patterns were greener under fluorescent illumination than under illuminant A.

These chromaticity changes exaggerated the changes in appearance of the patterns with change in illumination, since a considerable degree of compensation occurred through the eye becoming adapted to the illuminant. More extensive work on adaptation was required before an accurate assessment of the compensation could be reached, but some work had been reported by Helson and Grove (J. Opt. Soc. Am., 37, 387, 1947) in which Munsell patterns under illuminant A seen in one booth had been matched by patterns under

illuminant C as seen in another booth. He had made a rough attempt, on the basis of this work, to show, by the arrowed lines from A to A^1 for each pattern in the diagram, how far a pattern under illuminant A as seen by an "A-adapted" eye acquired the same apparent chromaticity as the same pattern under illuminant C as seen by a "C-adapted" eye. This seemed a quite fundamental question in discussing colour rendering and he thought fluorescent lighting should be the subject of study along these lines.

A further point related to the method of calculating the colour rendering of fluorescent lamps. The division into eight bands, mentioned by the author, was provisionally agreed when the C.I.E. met in 1948, but he wished to emphasise that it was only provisional, since a recommendation had been made that other methods should be explored. It might well prove that the eight-band division was not entirely adequate because of the presence of the mercury lines in the spectrum. However, that was a matter for straightforward test, and Miss Nickerson had indicated that she could provide him with the actual energy curves for the three American lamps referred to, as well as the spectral reflection curves for the Munsell patterns. Computation would then show how far the eight-band calculation would agree with accurate calculations of the chromaticities of the Munsell patterns. It would be interesting to learn from Mr. Harrison whether energy data for English fluorescent lamps was also available.

Lastly, there was the question whether the actual eight bands chosen were the best, and he thought we should keep an open mind on that, too. He had heard from Professor le Grand in France that he had made calculations with a different division of the spectrum into eight bands and had found the result was a closer approximation than with the present eight. Therefore, it was to be hoped that the situation would be kept sufficiently fluid so that when the next C.I.E., meeting took place, it would be possible to choose a method of calculating colour rendering on merit and not because a certain system had come into fairly general use.

MR. G. GRENFELL BAINES made the following written contribution to the discussion: it was read to the meeting by the Secretary. My contribution to this discussion can add nothing to the scientific aspect of the paper—much of it is far beyond me—but I am pleased to say something as an architect, in which capacity I am a potential accomplice or victim.

On a previous occasion I have discussed with you the effects of artificial light and the means employed for its distribution on architectural forms and surfaces, but owing to the general nature of the paper I was able to say very little about colour.

It is obvious from Mr. Harrison's paper that the amount of knowledge in possession of engineers, and their capacity to overcome the technical problems of producing coloured light have, as with normal artificial light, largely outstripped developments in application. While there is considerable scope for colour variation in fluorescent lighting which appears to the layman as "normal light," for the purpose of these remarks I am going to assume that the flexibility mentioned in the paper means that practically any colour is at the disposal of the engineer. Now, more than ever, therefore, is the time to take stock; for with this new weapon at his disposal the engineer becomes an infinitely more powerful accessory, or menace, with equally good intentions in either case.

To the architect colour *cannot* be divorced from form and texture; there-

fore, even if the method of producing the light has no ill effect on spatial qualities and the distribution of the light does nothing to detract from surface character, the colour can either make or ruin the effect.

The colour reaction of most people is largely emotional; thus illogical differences of opinion are bound to be found. Even the best informed student whose emotions are conditioned by extensive knowledge and research, must be prepared to admit that, in the end, appreciation is a personal matter and therefore almost impossible to predict. For instance, I disagree with Mr. Harrison about yellow; to me the human complexion is no more yellow than is tea; but here possibly we are not arguing on the same grounds. I realise that the scientific way in which you measure colours must enable you to appreciate differences and assess colour values much more accurately than we, who rely largely on our instincts: these we *endeavour* to train, but never over-train or burden with scientific information, of which we have only time to obtain a dangerous smattering.

I am surprised at the author's note on preference for red and blue rather than yellow and green. I realise it is backed by a great authority, but from considerable experience of producing colour schemes, and my own and others' reaction to them, I have gained the impression that a scheme is objectionable either when it is too hot (that is when there is a preponderance of reds), or it is too cold (that is broadly speaking a preponderance of blues).

Again, we may not be speaking on exactly the same grounds, but I would say that it is generally desirable that the combined effect of the colour as seen in daylight (the condition for which most colour schemes are designed) and the colour of the light, should be neither too hot nor too cold. The addition of artificial light should not unduly reduce the reds or blues in the original colours. Your recent attempts to improve on the original daylight effect of the fluorescent lamp, especially for certain types of interiors, such as homes and hotels, show that you are fully aware of the dangers of bringing up the blues, especially in our cold climate.

Types of interior will always influence the colour effects; so will the time during which the interior is generally used, though there will always be scope for some variation. For instance, the soft and warm light required for most of the time in most living rooms could temporarily be relieved, or even replaced, by a multitude of coloured lights on a Christmas tree; while on the stage the harsh white footlight should always be dimmed and superseded by the red spot at the time of the murder. Murders and Christmas, however, only serve to underline the normality of our existence, and special lighting effects should do no more than temporarily transgress the general rules.

I will endeavour to give a few general rules.

With very few exceptions, interiors are designed to-day to serve as backgrounds to various activities rather than to dominate the people who are using the building. In decoration schemes, therefore, harsh, over-riding effects should be avoided; but the domination of one theme is always desirable .

Contrasts in colour are effective when a small amount of one colour is used to contrast against a large amount of another. For instance, a ruby red on the larger surface of an olive green dress could be most effective, but equal masses of ruby red and olive green would be suitable as a colour scheme possibly only for football jerseys.

Broadly speaking, cooler colour schemes will raise low ceilings and make small areas look larger; in the latter case only one of the wall surfaces needs to be cooled; the others may, and perhaps should, be warmed up by incandescent

light. Places for temporary occupation, such as foyers and circulation areas, can stand greater variations of warm and cold colour.

The apparent height of walls below cornice level can be affected by the shadow from the cornice—a warm, dark shadow will lower, and a cool, transparent shadow can raise. Schemes for introducing colour into shadows could also be attractive; here the linear source would be ideal.

Obviously in these cases it is safer to have the architect at hand. Even the most imaginative and skilled designers find each new colour scheme something of an experiment (they would not be worth their salt as designers if they did not), and consequently it is more than ever necessary to have the co-operation of the engineer at the outset. As suggested by the author, special temporary rigs for placing coloured lights to judge the effects would be very useful. I have no doubt that engineers will in the future co-operate with the British Colour Council to produce a report which gives the effects, under controlled conditions, of coloured lights on standard decoration colours; such a report would, I assure you, be as carefully treasured as the most exquisitely produced colour card of any paint manufacturer.

MR. HOWARD LONG said that this question of colour had two aspects. One was sensation—which was important in a general lighting scheme; and the other was colorimetry—which was important when dealing with colour matching. He mentioned this because the author had referred a good deal to colour temperature, which was to be deprecated. It was true that colour temperature had been used in America, but it was inappropriate for the fluorescent lamp.

The paper had brought out certain facts which had been somewhat clouded in earlier papers on the same subject. For instance, in connection with the mercury lines, the author had made it clear that the amount of light due to the mercury lines was of the order of 20 per cent. That was the sort of thing liable to upset one's calculations on colour-rendering of materials. Lack of understanding of the colour-rendering properties of fluorescent lamps had caused so much trouble that some fluorescent installations had been taken out. It was essential, therefore, that not only the members of the Society should appreciate the position but that the public should also.

Mr. Long thought that the eight bands had been introduced to cover up the spectral lines. It would be helpful if in the published paper the words "Spectral Band No." in the paper were placed at the head of column one in the various tables: the actual colours for the spectral bands might even be placed against their numbers.

In these days of restricted electricity supply lamp efficiency was important. It seemed that, having achieved a high efficiency with the fluorescent lamp, there was a tendency to try to go back and achieve the commercial colours which we had in the tungsten lamp previously and with a lower efficiency. Mr. Long's view was that the greatest advantage should be taken of the higher efficiency of the fluorescent lamp: we should not start reducing the efficiency unnecessarily in general installations. Mr. Long, in a communicated note, also drew attention to the important work on artificial daylight colouring for colour-matching done by the D.S.I.R. on behalf of the B.S.I.

MR. H. G. JENKINS referred to the beginning of the paper in which it was stated that not the least important of the features which had contributed to the success of the fluorescent lamp was the wide range of possible colours. As one of the people involved in the development of new colours, Mr. Jenkins' own view was that this wide range was a curse! It would be much better to

have only one colour suitable for general illumination. When one considers the range of fluorescent colours in this country, in America, and on the Continent, the position was a little worrying, because there was, in fact, very little real difference between them. There was a characteristic pattern running through all mercury fluorescent lighting, and if the source was hidden it was difficult to detect which colour was being used. At adequate illumination levels practically all of these colours were acceptable; it was worthy of note that in the United States high levels of illumination of the order of 50 to 100 lumens per sq. ft. are quite usual, and they did not appear to have any serious difficulties with the colour rendering of fluorescent lighting.

The trend of colour development of fluorescent lamps had been largely dictated by the effort to obtain high luminous efficiency, which could only be achieved by depressing the red and the blue and accentuating the middle region of the spectrum. In some ways this was a pity, because it was undoubtedly responsible for much of the criticism of the colour of fluorescent lighting. In Mr. Jenkins' view fluorescent lighting came into its own in producing colours close to natural daylight. Unfortunately, such colours were not acceptable for general illumination, for the reasons which the author had given, and they had been relegated to the field of colour-matching lighting. Perhaps the chief problem that faced us at the present time was to produce a really acceptable warm light for restaurant and domestic use. The author had referred to tungsten lighting as "acceptable," but Mr. Jenkins did not think it was; he regarded unmodified tungsten lighting as quite unsuitable for the purposes mentioned, as was demonstrated by the fact that discriminating users, for example in domestic circles, generally surrounded their tungsten lamps by pink or warm tinted shades to make the lighting warmer in tone and more acceptable. This involved a considerable sacrifice in efficiency, and in this connection in comparing the efficiency of fluorescent and tungsten lighting he thought the author was quite right in using a factor of 4, even allowing for the losses in gear and the incidental losses which had been referred to, because any comparison of efficiency should take into account the colour of the sources.

The author had repeatedly referred to the black body locus, and had perhaps given an exaggerated idea of its importance in fluorescent lighting. Mr. Jenkins suggested that there was no fundamental reason why the colour of a light source should lie on this curve. It so happened that the sources to which we had grown accustomed were on the black body locus, but in a generation or two the people who had grown up with fluorescent lighting might well look back on the sources whose colour co-ordinates lie on the locus as foreign and unnatural. In discussing energy or luminosity distributions of light sources the author had suggested it was better to refer to columns in tables rather than distribution curves. Having looked at the author's slides, he thoroughly disagreed. Surely it was generally accepted that the best way to present data was on a curve, and therefore he pleaded for a wide use of spectral distribution curves, as used in the States.

In Section 6.1 reference was made to the effect of current density on the light from fluorescent lamps; it would be a pity if the impression got about that there was a major colour difference in going from an 80- to a 40-watt lamp due to current density. The difference was only a second order one, and no greater than the difference which occurred in different batches of lamps of the same nominal rating and colour.

MR. J. G. HOLMES said that, while he was extremely interested in this paper, he was also somewhat disappointed. He was interested because there had

been such very rapid developments in fluorescent powders, particularly in this country, that it was very easy to get out of date, and the author had given a host of very valuable figures which would go a long way to bringing us up to date. He was disappointed, however, because in presenting this data the author had not indicated how his figures could be interpreted by those not already skilled in using them; the chromaticity co-ordinates were given in detail and defined the general overall colour-appearance of a lamp in terms which were readily understood, but these were not of the first importance because we very rapidly became adapted to differences in overall colour; the figures for relative luminance distribution in eight spectral bands gave a means of comparison between a particular lamp and one of the standard illuminants, but these by themselves were not any sure guide as to the suitability of the lamp for a particular purpose; the fundamental question of colour distortion by fluorescent lamps had not been approached on a quantitative basis, although it appeared from the summary of the paper that the colour-rendering properties of lamps would be related to their spectral distribution. It was, of course, possible for those skilled in the art to estimate the colour-rendering properties from the distribution of luminance in the eight spectral bands, but the author's introductory remarks had been entirely qualitative and no indication was given of the quantitative effects in colour-rendering. It was surely a fairly easy task in colour measurement to compare the actual colours of a few critical materials, such as yellow, green, or mauve papers, under a fluorescent lamp and under a standard illuminant of similar colour appearance and to assess the colour-rendering properties of the test lamp in terms of the differences in chromaticities, which could doubtless be correlated closely with the flux distributions in the eight spectral bands. These figures would tell us how much these colours were distorted by a fluorescent lamp. This information had not yet been published, although there had been several references to ways in which it could be expressed, notably by G. T. Winch and by P. J. Bouma, as long ago as 1936 (see Reference 2), and Dr. Wright had indicated that figures would soon be available for three types of American lamps.

The criticisms levelled against fluorescent lamps in the past eight years had nearly all been withdrawn, but with one notable exception, namely, the colour distortion of yellow, green, and blue materials. This problem of colour-rendering would have to be solved before fluorescent lamps were generally accepted without reservation, and it seemed to him that the more people there were who understood the differences, the more likelihood there would be of putting the differences in true perspective and eventually of solving them.

The author had referred to the choice of fluorescent lamp colours more purple than incandescent sources, and had explained this by comparison with the preference for red and blue colours so often reported by psychologists. This, however, was a completely different matter, and the fact that there was a preference for red and blue amongst the subjects of psychological investigation, often the illiterate, backward, or even insane members of the community, did not mean in any way that the rest of us would prefer purple light. The choice of colour should surely be settled on some more objective basis, such as by comparison with the British Standard Specification 950, 1941, or by research work such as he had just indicated. The British Standard Specification was generally regarded as applying to daylight matching units with filament lamps and some coloured absorbing media, but it could be equally applied to a fluorescent lamp. Data had been published for colour-rendering

under artificial daylight units using filament lamps, and this would be available for comparison with similar data for fluorescent lamps.

The author had given relative flux data for some of the standard illuminants, and it was appropriate to add some other figures for the sake of completeness. The figures for Illuminants B and C had been calculated to a high accuracy by Mr. T. Smith at the National Physical Laboratory for inclusion in the British Report on Colorimetry presented at the Paris meetings of the Commission International de l'Eclairage in June, 1948, and, as that report might not be published for some time, the figures were given in the table below. The figures for Illuminant A (2848 deg. K) and for the equi-energy source had also been calculated by the same method and were given in the table because those in the paper were not confirmed in the last decimal place.

Spectral Band	Wavelength Range (μ)	Percentage Flux			
		Standard Illuminant A (2,848 deg. K)	Standard Illuminant B	Equi-energy source	Standard Illuminant C
1	380–420	0.0056	0.01703	0.0306	0.02591
2	420–440	0.0584	0.17522	0.228_2	0.26301
3	440–460	0.247_0	0.64165	0.733_6	0.90900
4	460–510	5.357	9.21680	9.636	11.10310
5	510–560	33.49_3	39.30940	40.11_9	40.86439
6	560–610	42.70_1	38.15751	37.13_4	36.15438
7	610–660	16.58_5	11.57364	11.261	9.95403
8	660–760	1.553	0.90875	0.857_6	0.72618

The names given to the eight bands in Section 3.1, and in Fig. 2, were not quite consistent. Would it not be better to call Nos. 1 and 2 "Far Violet" and "Violet" respectively, and to call Nos. 7 and 8 "Red" and "Far Red" respectively? The use of the adjectives "light" and "dark" for the two red bands was not in accordance with their usual meanings.

Finally he referred to the use of colour temperature as a convenient label for fluorescent lamps. This was admittedly bad practice, and he felt that it should not be included in the Transactions of the Society for light sources which did not give an energy distribution conforming substantially to the continuous spectrum defined by Planck's law. The author had been most careful throughout most of the paper, emphasising the misconception in using colour temperature in Section 3.2, and again in Section 6.3, only to fall from his own high standard in the penultimate section. If a number were required, the chromaticity co-ordinate x would do equally well and might even be better than colour temperature, but surely it was not necessary to use a precise figure when lamps varied in practice. A much better scheme would be for the lamp makers to agree to names such as Blue sky, North sky, Daylight, Sunlight, Natural, and so on, referring to agreed areas on the chromaticity diagram, until such time as powders were available giving energy distributions closely comparable with those of a temperature radiator and therefore capable of being described by colour temperature figures.

MR. G. T. WINCH said he was particularly interested in this paper because he had for over ten years been concerned with the development of methods of measuring colour and colour-rendering properties of light sources, and it

was very satisfying to find this technique being used in the manner indicated in the paper.

Referring to the point mentioned by Dr. Wright and Mr. Holmes, namely. the interpretation of the colour-rendering properties from the luminance values in the eight spectral bands, Mr. Winch also hoped that Mr. Harrison would in due course be able to provide some information on this correlation.

In this general connection, however, it might be helpful to recollect the way in which the development had progressed. Most of the preliminary work on this method was carried out just prior to the war, and in order to provide a practical basis for routine measurements and industrial control of colour-rendering properties a decision had to be taken on what at that time appeared to be the best choice of spectral band intervals. Due to the war, however, development work had to be suspended between 1939 and 1945. Workers on the subject were now well aware of the possibility that the bands originally selected might not be the optimum bands, and he had himself made this point at the C.I.E. Meetings in Paris in July, 1948. He agreed with Dr. Wright that an open mind should be kept on this matter and hoped that would not be long before time could be devoted to extended investigations in this connection using the new forms of apparatus now available which had taken many years to develop to their present accuracy.

In the early days of the attempts to devise methods of measuring colour-rendering properties, that was back in 1937, he did some preliminary exploration of the possibility of correlating the C.I.E. chromaticity co-ordinates of coloured surfaces under different illuminants, but at that time it was not practicable to make measurements to the necessary accuracy at commercial speeds. He very much hoped that, as indicated in a paper presented to the C.I.E. in July, 1948, some extension of this method might be found which would usefully supplement the spectral band technique. He believed, however, that this spectral band data would still be used in the industrial control of colour-rendering properties of lamps, but he would like to see these data correlated with the colour appearance of objects under the more commonly experienced viewing conditions.

MR. A. W. JERVIS said that the real judge of colour must be the ordinary person and not the trained observer. As to the householder covering a tungsten lamp with a pink shade, he said he did not think that this was done to improve the colour rendering, but rather, perhaps, to hide the spaciousness of the room and make it more cosy.

On the general question of colour appreciation, he emphasised that it varied with the type of material that was being dealt with. For instance, the author was very careful with the colour samples shown to have all materials with a matt surface, but it had been found that when dealing with glossy surfaces the appreciation of the colour differences was more difficult on account of specular reflection. Again, individual tastes caused differences. Some people liked blue in their decorations, and their appreciation of a material with blue in it might be entirely different from another person's. When the daylight lamp was introduced, one of the great difficulties was that people did not appreciate it as such; they appreciated daylight with thousands of lumens per square foot, but when it came to 10 or 15 lm./ sq. ft., the effect was far from what they presumed it would be. Even an increase in the intensity of daylight fluorescent up to 50 lm./ sq. ft. had a greatly improved reception from customers, and the gloomy effect was greatly reduced.

Had the author, he asked, done any work on the difference of colour

appreciation under varying intensities of illumination, and was there any marked difference in the effect when comparing what was essentially the same coloured material, but with different dyes, under fluorescent lamps? Such information would be of great value in assessing this colour problem.

He thought that the author, in presenting such a paper, had gone a long way to help clarify the position, especially as in dealing with colour, the light source was only half the problem; the type of lighting, whether diffused, completely indirect or very hard direct lighting had a material effect on the resulting colour appreciation by the average individual.

MR. W. RAMSDEN questioned the use of the C.I.E. luminosity function in the specification of the colour-rendering properties of a radiation by the eight-spectral-band method, and suggested that a combination of the x, y, z distribution functions would be more satisfactory, as the colour of a surface is determined by the products of the energy distribution of the source, the reflection spectrum of the surface, and these three functions, i.e., not by the luminosity function alone.

DR. T. S. HENDERSON (*communicated*): The value of the eight-block diagram seems to be limited. It is difficult to see how it can be used as a manufacturing control, as Mr. Winch suggested, in view of the complexity of the apparatus required; while from the point of view of the phosphor expert it obscures the facts in which he is interested. The main mercury lines are absorbed into four separate blocks and it is impossible to estimate their joint effect. From a complete spectrum curve with the mercury lines superimposed on the phosphor bands, such as Mr. Donaldson has been obtaining at the N.P.L., it is possible to estimate the luminance and chromaticity of the phosphor alone, and of the mercury spectrum alone, as well as their combined effect. This separation of the two parts of the spectrum is important, for the contribution of the mercury lines varies not only in intensity, but also to some extent in chromaticity according to the phosphor present.

Another objection to the block diagram is that with certain spectral distributions the diagram may give a misleading picture of the spectrum and lead to false estimations of colour-rendering properties. Consider a spectrum with a wide trough covering four of the blocks. A narrow peak added to this, with its peak at the junction of the two inner blocks, could give rise to a diagram in which the four blocks considered were all of equal height or nearly so, which would be quite false representation. Such a spectral distribution, though unusual, is by no means impossible.

With regard to specifications of lamp chromaticities, the author's emphasis on the fact that the data are not necessarily applicable to any particular commercial lamp suggests that these specifications are targets at which manufacturers aim with a certain lack of precision. A recent survey of six "daylight" lamps made by different well-known makers showed a spread which may be roughly indicated as 4,500 deg. K $\pm$ 300 deg.; a very considerable variation. Much better control than this is required if types as close on the C.I.E. diagram as "daylight" and "natural" are to be kept distinct.

There seems to be some evidence for the usefulness of colours in the region below the black body locus, but these colours become more pleasant as x increases. Thus with x about .47 we have the "peach" colour which has found wide acceptance. Some makes of "warm-white" have recently moved in this direction; compare Fig. 5 of the present paper with Fig. 19 of

the paper by Winch before this Society (Trans. Vol. XI, p. 137, 1946), showing x to have increased from .422 to .435.

The 4,500 deg. K standard for daylight was adopted in this country about seven years ago and in the U.S.A. in about 1944. Other versions of "daylight" in this country have previously been much colder (see Winch's diagram, mentioned above, where "daylight" is placed at about 5,350 deg. K.). Standardisation of this colour is a useful advance if adequate colour control is exercised by makers.

My colleagues and I have made experiments on the use of magnesium tungstate lamps combined with low colour temperature tungsten lamps. Natural daylight could be imitated to the general satisfaction of those engaged on colour printing work, which has exacting standards. For general work, however, we accept the 6,500 deg. K standard mentioned by Mr. Harrison ("northlight," or in U.S.A. "daylight") which is satisfactory for most purposes. It seems unlikely that any one source or combination will suit all colour matching applications; in the same way the other lamp colours have their own limited spheres of application.

DR. H. H. BALLIN (*communicated*): I welcome Mr. Harrison's suggestion that the range of colours of fluorescent tubes should be limited; the increasing variety of colours is apt to bewilder the user and has to some extent discredited fluorescent lighting in the mind of the public.

Fairly widespread experiments carried out by my company and confirmed by recent experience in the United States would, however, indicate that the three colours suggested by Mr. Harrison will not be sufficient and that another should be added to meet the demand for a warm comfortable light. One of the American manufacturers has tried to imitate as closely as possible the colour of a filament lamp with a so-called "warmtone" tube but, for the reasons clearly stated by the author of the paper, a colour below the black body line has proved more acceptable and is now available on the market as "peach" colour.

I do not entirely share Mr. Harrison's satisfaction with incandescent lamps, particularly when used to augment natural daylight. Indeed, the ease with which the light from a 4,500 deg. K "daylight" tube blends with natural daylight must be considered one of the great blessing of this new light source and may decisively affect the construction of buildings in the future, as it redeems us from the bondage of the "daylight factor."

I agree with the author's statement that at low illumination levels the warmer colour is more acceptable than the daylight colour as far as our so-called temperate climate is concerned; I should be interested to hear his views as to whether the same considerations apply to a hot climate.

MR HARRISON, giving a brief reply to the discussion, said he quite agreed that scientifically the colour temperature should only be used for substantially a Planckian type spectral distribution.

He confirmed the point made by Mr. Jenkins that the colour difference between 80-watt and 40-watt lamps employing the same phosphor was small, in fact a second order difference.

The contributions of Dr. Wright, Mr. Holmes, and Mr. Winch had referred to measuring the effects of illuminants on coloured materials. This was a matter on which much work was required, and it was a difficult problem. The method described by Dr. Wright was akin to one he (the author) had demonstrated by puting coloured filters in front of the illuminants of the same

colour but of different spectral distribution. It might be that coloured filters could be used instead of patterns.

He would be glad to have the figures which Mr. Holmes had promised, and they would help to confirm, or otherwise, figures given in the paper.

On the question of colour preferences, it had been found that even blue calcium tungstate and red cadmium borate fluorescent lamps could be run together to illuminate a room, and the effect was not displeasing. On the other hand, a yellow or green fluorescent lamp would give a very displeasing effect.

As Mr. Jervis had indicated, factors such as intensity and the nature of the materials in a room could have an important bearing on the effect produced by an illuminant.

Further written reply by the author.

I am grateful to Mr. Grenfell Baines for suggesting some rules for achieving the desirable co-ordination of lighting with the architectural and decorative features of buildings. As emphasised in his contribution, colour appreciation is a personal matter. Nevertheless, it is often possible to predict from a knowledge of the spectral distribution whether an illuminant will give a pleasing effect. To take an exaggerated case, the sodium or mercury lamp is regarded as universally unacceptable from a colour point of view as a room illuminant. On the other hand an illuminant with a spectral distribution approximating that of sunlight is generally acceptable.

Sunlight is acceptable because in it the various colours are rendered in what we accept as a normal and pleasing manner with satisfactory colour contrasts.

The author's reference in the paper to the preference for "reds" and "blues" is not intended to suggest that the major part of room decorations should be in these colours; in fact no reference is intended to the illuminated scene, for its choice is generally in the hands of others than the illuminating engineer. But it is desirable in the rendering of colours by the illuminant for the "reds" and "blues" to appear at least normal; or if there is any emphasis it is preferable for them to appear slightly brighter than normal with respect to other colours.

With reference to the queries of other contributors on the choice of lamp chromaticities on the purple side of the black body locus it should be pointed out that the suggestion refers only to a slight displacement from the locus. The illuminants, such as "natural" and "warm-white," are near-whites.

The section on colour-matching illuminants in the present paper was confined to those employing fluorescent lamps, and there was no intentional omission of reference to the standardisation of "artificial daylights" by B.S.I. in, for example, B.S.S.950.

Mr. Jenkins mentions a matter of some importance in the desirability of limiting and rationalising the number of colours for general illumination. While, hitherto, the fluorescent lamp has been used mostly for industrial and commercial lighting its use is rapidly extending in the social and domestic field where the requirements are somewhat different. Probably standardisation could be achieved on one or two colours (e.g., 6,500 deg. K daylight), but standardisation of others would, in the author's view, be premature because of the extension of the fluorescent lighting field. The author has suggested that three colours might be adequate but would not quarrel with Dr. Ballin's desire to extend it to four. Three of four colours might be adequate to cover the near-white range, and eventually international standardisation should be

possible, although it should be remembered that different phosphors may be used.

The figure of 60,000 deg. K in the paper is no misprint, as blue skylight can attain a colour temperature of this order. It is, of course, not an ideal illuminant, but is acceptable if the illumination intensity is high.

One or two contributors have expressed a preference for the energy distribution curve rather than the eight-band luminance data. In the author's experience the eight-band method has proved a very valuable tool for both control and research. In a few special cases the full spectrophotometric curve may be desired, and there is, of course, no reason why this should not be obtained, even if eight-band data is normally taken. A number of instruments have facilities for taking either the full energy curve or the eight-band luminance measurements. However, a method of abridged spectrophotometry offers considerable advantage in the rapidity with which measurements can be made. If a better method of specifiying the spectral distribution than by the present eight bands is forthcoming it will undoubtedly be considered on its merits at the next C.I.E. meeting, for, as Dr. Wright has indicated, the position is still open. In reply to Mr. Ramsden, while the specification of the spectral distribution in terms of luminance results in some bands having very small numerical values the chief use of eight-band data is in making comparisons between illuminants, and this can be done as readily with luminance data as with that based on any other function.

Mr. Holmes has suggested the names "Red" and "Far Red" for bands seven and eight, and these would appear to the author to be an improvement on the terms hitherto used. The suggestion that fluorescent lamps should be judged by comparison with B.S.S.950 might not be suitable in the case of lamps other than those for colour matching. Experience has shown a definite preference for fluorescent lamps for general lighting having chromaticities slightly on the purple side of the black-body locus. In addition, as mentioned in the paper, the colour of a fluorescent lamp is often a compromise because factors such as efficiency and maintenance have to be taken into account.

The choice of the lamp colour for colour matching work is interesting, as it has been dictated by the colourists who in the past have invariably worked under north skylight. They have insisted that any artificial illuminant shall give comparable conditions, and it has been found that illuminants of equivalent colour temperature in the range 6,500 deg. K—8,000 deg. K are preferred over those below 6,500 deg. K.

A number of contributors raise the matter of the correlation of spectral band data with the effects of the illuminant on coloured materials, and Dr. Wright has indicated certain work which is being done. It might be mentioned that work on similar lines was suggested by British workers in this field, soon after the introduction of the fluorescent lamp, as indicated by Mr. Winch. Whilst much valuable data may be obtained by measurements of chromaticity of various colour samples under illuminants to be compared, and the assessment of relative colour differences taking into account eye adaptation, the final step in the correlation will be to determine what colour changes are permissible on the various samples. This may well require a kind of public opinion test such as is already employed in the qualitative assessment of experimental fluorescent lamps.

Additions to List of Members

The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members:—

SUSTAINING MEMBERS:—

R. and A. G. Crossland, Ltd. ..... *Representative*: F. M. Cocksedge.
Cartbridge Lane, Walsall, STAFFS.

Satchwell and Gittings, Ltd. ..... *Representative*: A. E. Gittings.
Tantarra Electrical Works,
Walsall, STAFFS.

CORPORATE MEMBERS:—

Baines, G. G. .....60, West Cliff, Preston, LANCS.
Bicket, J. H. .....424, Stanley Road, Bootle, LIVERPOOL.
Cluney, A. F. ....."Homelands," Testwood Lane, Totton, SOUTHAMPTON.
Cooke, C. A. .....96, Park Lane, Linacre Park, LIVERPOOL.
Davies C. H. ....Tyn-y-Coed, Meadow View, Haverfordwest, PEMBS.
Duncan, P. A. ....."Bay View," 39, Rotherslade Road, Langland Bay, Mumbles, SWANSEA.
Dunham, K. R. .....Flat 1, "Ellerslie," Riley Crescent, Penn, WOLVERHAMPTON.
Fieldhouse, F. N. .....98, Sandown Road, Belfast, N. IRELAND.
Harrison, V. G. W. ...Printing, Packaging and Allied Trades Research Association, Randall Road, Leatherhead, SURREY.
Knox, W. S. .....2, Moorcroft Avenue, Oakworth, Keighley, YORKS.
Lilley, H. G. .....British Thomson Houston Co., Ltd., 8 John Bright Street, BIRMINGHAM.
Lloyd-Jones, A. E. ...Curwen Stores, Gwaun-Cae-Gurwen, S. WALES.
Manship, L. W. .....73, Maney Hill Road, Sutton Coldfield, WARWICKS.
Pegg, E. E. .....16, Talbot Road, SOUTH TOTTENHAM, N.15.
Pulvermacher, F. H. ...Brynhyfryd, The Soar, Pentyrch, CARDIFF.
Richards, D. S. .....210, Mount Vale, YORK.
Rogers, H. D. .....11, Sunbury Avenue, Penwortham, Preston, LANCS.
Seaden, E. R. .....11, Frederick Road, Gravelly Hill, Erdington, BIRMINGHAM.
Shaddick, A. G. .....56, Hazelhurst Road, Llandaff North, CARDIFF.
Sinclair, A. V. .....Ael-y-Bryn, Limeslade Bay, Mumbles, SWANSEA.
Springett, R. H. .....The Quay, Cromwell Lane, Tile Hill, Coventry, WARWICKS.
Tate, R. L. C. .....Vineyard House, Richmond, SURREY.
Walker, E. ....."Cherry-Garth," 27, Nook Road, Scholes, LEEDS.
Williams, W. G. .....11, Durban Avenue, Christleton, Nr. CHESTER.

Register of Lighting Engineers

The Council have accepted the following applications for inclusion on the Register of Lighting Engineers:—

A. W. Gostt, H. Hazel, G. V. Malon, J. A. H. Studholme.

Corporate Members are reminded that those wishing to make application for inclusion in the Register under Regulation 6, whereby the educational requirements may be waived for those with approved practical experience, must do so before February 1, 1950, after which date all applicants will be required to hold the Intermediate Certificate of the City and Guilds of London Institute in Illuminating Engineering.

The Annual General Meeting

The annual general meeting of the Illuminating Engineering Society was held at the Royal Society of Arts, John Adam-street, London, W.C.2, at 6 p.m., on Tuesday, May 10, 1949.

The Secretary having read the notice convening the meeting and the statement of the auditors for the past year, it was agreed that the minutes of the last meeting be taken as read and were approved.

Report and Accounts for 1948

The President presented the report of the Council for the year 1948 and drew attention to the two outstanding events of the year: the Society's first summer meeting which was held at Harrogate during June, and the institution of the Register of Lighting Engineers as a hallmark of a qualified practising lighting engineer. In addition the educational programme of the Society had resulted in more courses for the City and Guilds examinations in illuminating engineering, and lectures to school children had been given in many parts of the country.

The following resolution was then put to the meeting by Mr. C. W. M. Phillips and seconded by Mr. N. C. Slater:—

> That the report of the Council and the accounts of the Illuminating Engineering Society for the period January 1, 1948, to December 31, 1948, be hereby adopted, and that a vote of thanks be extended to the President, Council and Officers for their efforts on behalf of the Society during the past year.

The resolution was put to the meeting and the report was declared carried unanimously.

The President, on behalf of the Officers and Council, expressed his appreciation of the vote of thanks.

On the proposal of Mr. E. S. Evans, seconded by Mr. H. V. Crosse, Messrs. Robert J. Ward and Co. were unanimously re-elected as auditors of the Society for the year ending December 31, 1949.

Election of Officers and Council

The President then reported that in accordance with the Articles of Association the list of Council's nominations to fill the vacancies on the Council at the beginning of the next session had been notified to members after which an independent nomination had been made under Article 48. A postal ballot of members had therefore been held as a result of which the following were elected:—

Mr. H. G. Campbell, Mr. W. J. Wellwood Ferguson, Mr. C. A. Hoskins, Mr. J. N. Hull, Mr. A. W. Jervis, Mr. E. B. Sawyer, Dr. W. S. Stiles, Mr. D. A. Strachan.

The President also reported that there having been no further nominations for Officers the Council's nominations were duly elected. Since the election, however, Mr. J. S. Preston found that owing to unforeseen circumstances he was unable to serve as President and had asked the Council to accept his resignation, which they had done with great regret. The Council therefore proposed in these unusual circumstances to appoint Dr. J. N. Aldington, who would have been the Senior Vice-President, to fill the vacancy of President, and to appoint Mr. W. R. Stevens to fill the resulting vacancy in the office of Vice-President.

Mr. A. G. Higgins said that he thought that the Council had acted very wisely and in the interests of the Society in dealing with this matter for which there appeared to be no precedent in the Society and he proposed to the meeting that they endorse the action of the Council in nominating Dr. J. N. Aldington and Mr. W. R. Stevens to fill the casual vacancies occasioned by the resignation of Mr. J. S. Preston. This was

seconded by Mr. F. M. Hale and carried unanimously.

The President expressed the appreciation of the Council for the support of the meeting.

The Officers for the Session 1949-50 were therefore as follows:—

President: Dr. J. N. Aldington.

Vice-Presidents: Mr. L. J. Davies, Mr. C. R. Bicknell, Mr. W. R. Stevens.

Hon. Treasurer: Mr. J. G. Holmes.

Hon. Secretary: Mr. H. C. Weston.

Hon. Editor of the Transactions: Mr. W. R. Stevens.

Fellowship

The President then announced the result of the ballot which had recently taken place in connection with the proposal to amend By-law 11 which dealt with the conditions under which members of the Society might be admitted to Fellowship.

The total number of votes in favour of the proposal was 749, the number of votes against being 118. The proposal to amend the By-law was therefore carried.

This terminated the formal business.

Address by M. Gaymard

The President said that it was a tradition of the Society after the annual general meeting each year for an address to be given by some distinguished person on a subject in which he had specialised. It was also a tradition that the speaker should be from overseas and on this occasion the Society were very glad to have with them M. Ludovic Gaymard, who was Chief Engineer of the Street Lighting Department of Electricité de France and President of the Association Française Des Eclairagistes.

In his address M. Gaymard dealt with lighting equipment and street lighting practice in France and stressed that whereas in England emphasis is placed on the efficiency of the equipment and installation as a whole, in France a main consideration was that of aesthetics. For instance, though mercury and sodium vapour discharge tubes are used extensively in this country for lighting in towns, in France these light sources are used only on main highways the colour rendering of such lamps being objectionable in towns. In Paris, he said, pavement obstructions and unsightly lamp columns are reduced to a minimum by fixing lanterns on wall brackets where possible.

Following the address a vote of thanks to M. Gaymard was proposed by Dr. J. W. T. Walsh, who said that the Society was sincerely grateful to M. Gaymard for the honour he had done them in coming to this country and giving such an excellent address. He said that there was much to be learned on the subject of street lighting and the exchange of ideas between countries was most valuable. He asked M. Gaymard as President of the French society to convey to his colleagues in France the sincere greetings and good wishes of the Illuminating Engineering Society of Great Britain. In conclusion he congratulated M. Gaymard on the excellent manner in which he had presented his address.

The vote of thanks was seconded by Mr. R. O. Ackerley, who also said how much he had enjoyed the address. He had been particularly interested in M. Gaymard's approach to the aesthetic aspect as he was sure that one thing that lighting engineers must learn was the way to blend science and art. He also congratulated M. Gaymard on his foresight during the time of the occupation so that full street lighting could be restored in Paris with the minimum of delay.

The President also paid tribute to M. Gaymard saying how much he had

enjoyed his own visit to the French society a few months ago and how much he welcomed this co-operation between the two societies.

M. Gaymard expressed his appreciation of the vote of thanks and of the very warm welcome which had been extended to him.

Sessional Meeting in London

A sessional meeting was held at the Lighting Service Bureau, 2, Savoy-hill, W.C.2, on Tuesday, March 8, 1949, at 6 p.m., when the President, Mr. J. M. Waldram, took the chair.

The minutes of the last meeting were taken as read and approved, and the secretary announced particulars of forthcoming meetings.

The President then announced that the Council of the Society had nominated Mr. Howard Long to be an honorary member of the Society. He said that Mr. Long's work in promoting the objects of the Society was well known, Mr. Long having played a very active part in the formation of I.E.S. Centres and Groups in various parts of the country. The President recalled that there were at present no honorary members, the distinction having last been held by the late Mr. A. P. Trotter and the late Mr. J. S. Dow.

Mr. Long, in accepting the honour, said he was deeply conscious of the responsibility to maintain the high traditions of such a distinction. He said that he felt the greatest pleasure and pride, and thanked the Council and members of the Society for the very high honour they had conferred upon him.

The President then called upon Mr. W. Harrison to present his paper entitled "The Colour of Fluorescent Lamps." The paper discussed the colour rendering properties and the specification of the colour of illuminants. The author gave reasons for the present colours used for fluorescent lamps. The paper also discussed developments in the provision of artificial daylight colour matching and gave the eight spectral-band and chromaticity co-ordinate data for the principal phosphors employed in fluorescent lamps.

After a vote of thanks proposed by the President, the discussion was opened by Dr. W. D. Wright, following which the secretary read a contribution from Mr. G. Grenfell Baines, who unfortunately was unable to be present at the meeting. Other speakers in the discussion were Mr. Howard Long, Mr. H. G. Jenkins, Mr. J. G. Holmes, Mr. G. T. Winch, Mr. A. W. Jervis, and Mr. W. Ramsden. The author replied to the discussion and the meeting was closed.

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form :—" Trans. Illum. Eng. Soc. (London)."

Printed by
ARGUS PRESS, LTD.,
Temple-avenue and
Tudor-street,
London, E.C.4.
England